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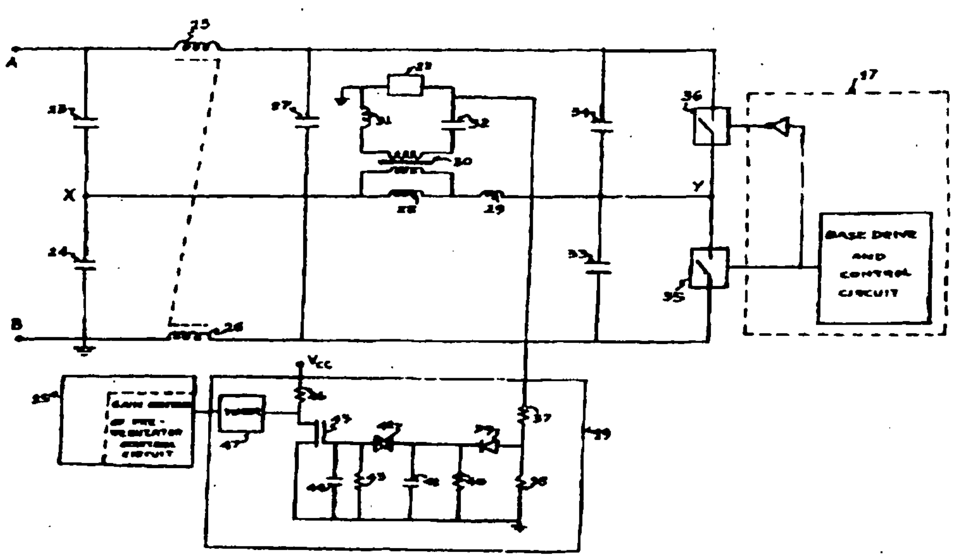
(54) Title: A POWER PROCESSOR FOR METAL HALIDE LAMPS




(57) Abstract

A power processor (16) for igniting a metal halide lamp (22). The power processor (16) provides for reliable ignition and stable flow to arc transition of the metal halide lamp. The lamp voltage includes a fundamental sinusoidal component, a linear switched component and a higher order odd harmonic component. The higher order harmonic component is reduced once ignition of the lamp (22) occurs and the fundamental sinusoidal component produces a stable arc. Lamp and circuit protection is provided by sensing the lamp voltage and reducing voltage to the lamp during a hot restrike condition.

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# A POWER PROCESSOR FOR METAL HALIDE LAMPS

The present invention is directed to a circuit for providing an operating voltage and current to a metal halide lamp. Specifically, a power processor is described for supplying a starting voltage and current to a metal halide lamp as well as steady-state voltage and current following starting of the lamp for maintaining a stable arc in the lamp.

Metal halide lamps are used widely in industrial applications, wherein high intensity, high efficiency lighting is needed. However, metal halide lamps present unique problems to the power supply designer because of the non-linearity of the impedance of the lamp. The impedance curve of the metal halide lamps are extremely non-linear and during ignition of the lamp present a chaotic load which must be matched in all stages of operation in order to provide the required arc stability.

Metal halide lamps are supplied with voltage and current from a high voltage inverter and power factor correction circuit. The high voltage provided by the power factor correction circuit is preregulated and converted to an alternating voltage and current for igniting the lamp and maintaining the lamp ignited.

The power processor circuit for generating the lamp voltage and current from the voltage supplied by the power factor correction circuit must provide the correct operating power during all phases of lamp operation. These phases include the initial start-up mode wherein a voltage and current having a high odd harmonic content applied to the lamp results in ignition of the lamp. During the following normal working mode phase, arc

stability must be maintained, requiring a current which does not have a high harmonic content.

An operating phase which must be accommodated by the power processor includes supplying a safe voltage level to restart ignition during a hot restrike condition. Under these conditions a continuous starting voltage to the lamp may damage the thermal switch and the shunting resistor inside the lamp if the lamp takes an inordinate amount of time to ignite.

Thus, in recognition of these unusual operating conditions for the metal halide lamp, i.e., a starting mode, a working mode, and a hot restrike condition or open load condition, a power processor is needed which can provide the voltage and current to a metal halide lamp for all phases of operation.

## Summary of the Invention

It is an object of this invention to provide a power processor for igniting a metal halide lamp.

It is a specific object of this invention to provide a power processor which supplies an optimum starting mode voltage and current to ensure a definite glow to arc transition for a metal halide lamp.

It is a further object of this invention to provide a power processor which protects the lamp and the processing circuitry from excessive voltage and current during a hot restrike or an open load condition.

It is also a further object of this invention to provide a power processor

which can dim the metal halide lamp brightness.

These and other objects of the invention are provided for by a power processor which produces an optimum starting mode for igniting the metal halide lamp, and which includes circuitry for protecting the lamp and power processor during a hot restrike and a no lamp condition. In carrying out the invention, circuitry is provided for applying a voltage and current having a fundamental frequency component, linear ramp component, and an odd harmonic of the fundamental frequency. All three components are superimposed on each other as a starting current. The harmonic component quickly damps out after lamp ignition, depending upon the slope of the fundamental frequency of the current which is determined by a resonant link of the power processor. The quickly-damped odd harmonic frequency current component leaves a fundamental frequency current which stabilizes the lamp current.

In carrying out the invention in accordance with the preferred embodiment, the power processor includes a modified Class E half-bridge configuration with a preregulator. The power processor provides an alternating switched high voltage from the preregulator to the lamp. During the starting mode, the harmonic content of the current is kept high. The result of a voltage at a fundamental frequency and a current with a high harmonic component is harmoniously increasing power punches applied to the lamp electrodes improving electrode life. While igniting, the current pulled from the preregulator is maintained low which produces a reduced amplitude fundamental frequency current but the harmonic components are maintained rich by resonating the load which includes the lamp. Once the lamp ignites the fundamental frequency current component increases,

storing more energy in a leakage inductance of the power processor. This leakage inductance damps the load resonance, giving higher harmonic content during switching transitions of the power processor, and decreasing it as the slope of the fundamental changes. Dimming of the lamp brightness is achieved by preregulation of the DC bus voltage without effecting the power processor fundamental frequency of operation.

In the present embodiment, the lamp is protected during hot restrike from excessive power which may damage the shunting resistor and the thermal switch of the lamp by monitoring the load voltage and varying the gain of the preregulator controller. This brings the DC bus voltage within the safe limit of the lamp.

## Description of the Figures

Figure 1 illustrates the functional block diagram of a circuit for producing current and voltage to illuminate a metal halide lamp in accordance with the present invention.

Figure 2 illustrates the details of the power processor and its hot restrike protection circuitry.

Figure 3 illustrates the modified half-bridge Class E topology of the circuit of Figure 2 during the normal working mode.

Figure 4 illustrates the modified half-bridge Class E topology of the circuit of Figure 2 in hot restrike condition.

Figure 5 illustrates the various voltage and current waveforms in the power

processor circuit when igniting the lamp.

Figure 6A illustrates the lamp voltage characteristics as a function of time during the various operational phases of the lamp 22.

Figure 6B illustrates the lamp V and I characteristics as a function of time during the GTA and stead-state conditions of lamp 22.

Figure 7 illustrates the voltages and currents of the power processor of Figure 2 during the flow-to-arc (GTA) and before local thermal equilibrium (LTE) mode of the lamp.

Figure 8 illustrates voltages and currents of the power processor of Figure 2 under normal operation of the lamp (LTE mode).

Figure 9 illustrates voltages and currents of the power processor of Figure 2 under hot restrike condition of the lamp.

## Description of the Preferred Embodiment

Referring to Figure 1, there is shown a circuit for providing a voltage and current to a metal halide lamp. The circuit includes a DC power supply 11 which is connected to a source of AC voltage 10. The DC power supply provides for a voltage +Vcc which is used to power the automatic power factor control (APFC) circuit 14, preregulator control circuit 15, control circuit 17 for power processor 16 and hot restrike control circuit 19. A boost choke of APFC power circuit 12 will chop the DC voltage supplied by the DC power supply +Vbb. This chopped DC voltage is given to a preregulator which produces therefrom a high voltage potential Vab.

Power factor correction is employed so that changes in load represented by the lamp 22 and power processor 16 will maintain nearly unity power factor to the input voltage line 10.

The arrangement of the DC power supply boost choke circuit 12 and power factor correction circuit (APFC) 14 is well known in the art and finds extensive use in the generation of voltages for driving metal halide lamps.

The high voltage from APFC power circuit 12 is altered by a preregulator power circuit 13. The APFC power circuit 12 is controlled by an APFC control circuit 14. The APFC control circuit 14 is provided with a voltage sense from DC bus Vab and gain control from the preregulator control circuit 15. The preregulator control circuit 15 receives signals from the DC bus Vab and the hot restrike control circuit 19. The hot restrike control circuit 19 continuously monitors the lamp voltage 21 and changes the gain of the preregulator control circuit 15 so as to maintain the DC bus Vab such that it remains within the safe limits of lamp 22 after being processed by a power processor 16 and the resonant network 18.

The DC bus voltage Vab is applied to the power processor 16. The power processor 16 employs a modified Class E half-bridge topology. The output 20 of power processor 16 is connected to a resonant network 18. This resonant network 18 offers an inductive load to the processor output 20 and a capacitive load to lamp input 21. The power processor 16 receives the switching commands from the control and drive circuit 17.

Figure 2 illustrates the power processor 16 and its interconnection with the control and drive circuit 17 and hot restrike control circuit 19. Terminals

A and B receive the DC high voltage from preregulator power circuit 13. Capacitors 23 and 24 couple each terminal A and B to one side of the primary of transformer 30. The other side of the primary of transformer 30 is connected through a leakage inductor 29 to the common junction between two electronic switches 35 and 36. Switches 35 and 36 are alternately operated from a base drive and control circuit 17. Under operation of the base drive and control circuit 17, a current source formed from inductors 25 and 26 coupled together provide a driving current through leakage inductor 29, the primary of transformer 30 to the common connection of capacitors 23 and 24.

Dimming is effected in block 14/15 of Figure 1. The DC bus voltage is varied by maintaining the reference voltage to the error amp of APFC control circuit 14 constant and varying the potential divider network of voltage VAB (voltage sense as indicated in Figure 10.

The secondary of transformer 30 is connected to an inductor 31 and capacitor 32 which supplies current to the metal halide lamp 22. A magnetizing inductor 28 is connected across the primary winding of transformer 30.

The alternate switching of electronic switches 35 and 36 produces a linear ramp current by means of the magnetizing inductor 28 and leakage inductor 29. This linear current, in turn, makes the capacitor 27 serving as a switch link capacitor, resonate at a fundamental frequency determined by the mutually coupled inductor, transformer primary with reflected reactance and the link capacitor to decide the fundamental frequency. The linear ramp is also controlled by the mutually coupled inductor and magnetizing

inductor 28. A rectified sinusoidal voltage appears across capacitor 27.

The electronic switches 35 and 36 are switched at a rate of nfl, where n is practically selected to be 1 or 2, and fl is the resonant fundamental frequency. It has been found that above 50 KHz there is good arc stability.

It has been observed that for better stability of arc, a quick damped odd harmonic content of current is required. The damping rate is decided by the amount of power in the leakage inductor wich in turn is decided by the rate of change of current (i.e., dominantly the slope of the ramp).

$$\text{Power} = L \times I \times \frac{di}{dt}$$

Figure 4 illustrates how the three currents are produced I1, I2 and I3, and superimposed over one another for driving the load 48, constituting the circuit connected to the secondary of transformer 30. In a normal working mode, this secondary impedance will be reflected as a capacitance 48 across the magnetizing inductor 28. I3 represents the resonant frequency current component, I1 represents a linear ramp component of the current through the transformer 30 and its load circuit 48. A further, seventh or odd multiple harmonic I2 is produced from the secondary circuit components including inductor 31 and capacitor 32. As the lamp turns on, the Q factor of this series resonance circuit is reduced, and the magnitude of the seventh harmonic component I2 is correspondingly reduced.

The power processor circuit is a modification of Class E topology, it offers a minimum switching stress on said first and second switching elements and it being a modification of current driven topology, provides regulated current to said lamp load, a thing very much wanted during starting to

avoid damage to or avoid reduced lamp life.

The operation of the circuit of Figure 2 in the manner explained with respect to Figure 3, provides for arc stability by having the various superimposed components of the current through the lamp. The odd or seventh harmonic component provides for electromagnetic energy which assists in initiation of the arc. The linear current function tends to stabilize the arc, avoiding any loss of ignition. The fundamental frequency signal also contributes to the arc stability.

During a hot restrike mode, wherein the lamp ignition has been lost, the reflected impedance from the secondary of transformer 30 is no longer capacitive as shown in Figure 4, as capacitor 48, but rather the seventh harmonic or other higher order harmonic signal I2 increases in value as the load presented is that of a resonant circuit having a frequency resonance of the seventh or higher order harmonic. Once the lamp ignites the normal working mode is again entered in Figure 3 and the reflected impedance represented by capacitor 48 reappears, dampening the seventh harmonic in conjunction with the leakage inductor 29.

The hot restrike control circuit 19 detects the voltage on the metal halide lamp 22. As this potential increases, indicating a hot restrike condition, a voltage is produced across voltage dividing resistors 37 and 38. The rectifier 39 produces a DC voltage across resistors 40 and capacitor 41. A diac 42 produces a switching potential for the field effect transistor 45. The gate electrode of the field effect transistor 45 is connected to the parallel combination of resistor 43 and capacitor 44 and receives the switching signal from diac 42.

In the presence of a hot restrike condition, a monostable multivibrator, represented by timer 47, is triggered if the voltage remains for a period of time set by said resistor 43 and 44. During a time-out period set by the timer 47, the gain of the preregulator control circuit 15 is reduced, thus reducing the potential across terminals A and B. The reduced potential protects the circuitry of Figure 2 from excessive voltages which may damage the circuit during a hot restrike condition, as well as protecting the metal halide lamp from being damaged.

The various signals generated by the circuit of Figure 2 are shown in Figure 6. Figure 5 illustrates the voltage across capacitor 27 which is the fundamental frequency component I1, generated by Figure 2. As a result of the switching of electronic switches 35 or 36, the current through inductors 25 or 26 produce a linear, harmonic and first fundamental frequency component, as shown. This current is switched by switches 35 or 36 and applied to the primary of transformer 30.

Figure 6A illustrates the voltage across the lamp 22 from the time the lamp changes from the off-state to the normal working on-state. During the hot strike interval, voltage is applied to the lamp containing the seventh or higher order harmonic voltage. Once the glow to arc transition begins, the lamp impedance is reduced significantly, also reducing the seventh harmonic component. Finally, during the lamp on condition, the voltage has stabilized to approximately 30% of the voltage needed to strike the lamp.

Figure 6B illustrates the current through the lamp 22, as well as the voltage across the lamp 22 during each of the phases of off, glow to arc transition,

and lamp on.

The circuit of Figure 2 provides for increased stability as a result of the multicomponent nature of its voltage applied to the metal halide lamp 22. During each of the phases of lamp operation in which a chaotic load is experienced, the various individual components of linear, fundamental and seventh or higher harmonic component play a significant role in operation of the lamp.

Figure 7 illustrates the various voltages and currents generated in the circuit of Figure 2 during the glow to arc discharge phase of the lamp following the start-up phase. As a comparison, Figure 8 illustrates the various currents and voltages in the circuit elements of Figure 2 for the normal working mode of the lamp. As the comparison of these two Figures will illustrate how the higher order harmonic current component is diminished as the lamp goes from the glow to arc to the normal working on condition. During a lamp hot restrike condition, which is shown in Figure 9, very high harmonic components of current are produced in the dead time region of switches 35 and 36.

There has now been described with respect to one embodiment a circuit for providing an operating voltage and current to a metal halide lamp. Those skilled in the art will recognize yet other embodiments described more particularly by the claims which follow.

What is claimed is:

1. A power processor for igniting a metal halide lamp comprising:

first and second capacitors connected in series to form a common terminal, and connected across first and second terminals of a preregulator circuit;

first and second mutually coupled inductors connected to said first and second terminals of a preregulator circuit and to opposite sides of a switch link capacitor;

first and second electronic switches connected in series across said first and second terminals for alternately connecting said first and second terminals of the link capacitor to a common connection of said switches; and,

a transformer having a primary winding connected in parallel with a leakage inductor, and in series with a primary magnetizing inductor, said primary winding and magnetizing inductor being connected between said common terminal of the capacitors and a common connection of the switches, said transformer having a secondary winding connected to a series resonant circuit comprising a inductor element, coupling capacitor and the metal halide lamp, said resonant circuit oscillating at an odd harmonic of a resonant circuit comprising said switch link capacitor, and said magnetizing inductor.

2. The power processor of claim 1 further comprising a controller for

alternately switching said first and second electronic switches into conduction during alternate time periods.

3. The power processor of claim 1 wherein the transformer magnetizing inductance and the leakage inductances control the magnitude of a fundamental and harmonic current supplied to said metal halide lamp.

4. The power processor of claim 1, wherein said coupling capacitor is connected to one end of said secondary winding, said inductor element is connected to a remaining end of said secondary winding and said metal halide lamp is connected to remaining ends of said inductor element and coupling capacitor.

5. The power processor of claim 1 further comprising a means for sensing the voltage across said metal halide lamp and means for controlling said preregulator to lower a voltage from said preregulator when said voltage across said metal halide lamp exceeds a predetermined threshold for a minimum time interval.

6. A power processor circuit for driving a metal halide lamp comprising:

a power factor circuit for supplying a high voltage for igniting a metal halide lamp;

a preregulator receiving said high voltage and connected to first and second series connected capacitors;

the first and second capacitors having a common connection connected to one end of a transformer primary winding;

mutually coupled first and second inductors having first ends connected to first and second terminals for receiving said high voltage, and having second ends connected to a capacitor means forming a resonant circuit therewith;

first and second series connected switching elements connected across said capacitor means, said first and second switching elements alternately connecting each end of said capacitor means to a leakage inductor in series with said primary winding of said transformer;

a series resonance circuit connected to the secondary of said transformer, comprising an inductor and a capacitor, one end of said series resonant circuit being connected to one of said first and second terminals serving as a common terminal and being coupled to said metal halide lamp; and

a controller and base drive circuit connected to alternately enable said first and second switching elements to produce an alternating current through said primary winding of the transformer to produce a linear ramp current, a fundamental sinusoidal current and a damped harmonic sinusoidal current which is supplied to said halide lamp.

7. The power processor circuit of claim 6 wherein said mutually coupled inductors approximate a controlled current source

generating a substantially square current wave which interacts with said capacitor means to produce a sinusoidal current component.

8. The power processor circuit of claim 6 which provides a dominant fundamental resonant voltage and seventh harmonic current for producing increasing power punches to the lamp in each cycle during starting mode.

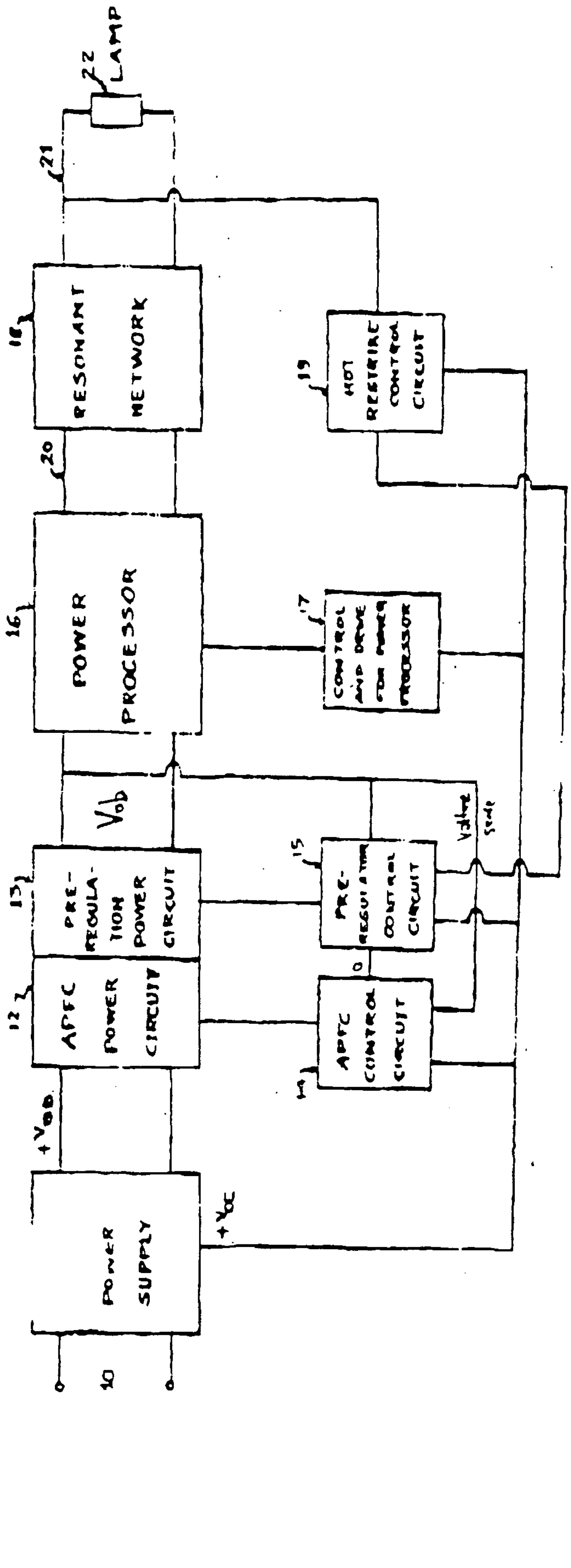

22 LAMP
21
18 RESONANT NETWORK
20
16 POWER PROCESSOR
17 CONTROL AND DRIVE FOR POWER PROCESSOR
19 HOT RESTRIKE CONTROL CIRCUIT
13 PRE-REGULATION POWER CIRCUIT
15 PRE-REGULATOR CONTROL CIRCUIT
12 APFC POWER CIRCUIT
14 APFC CONTROL CIRCUIT
POWER SUPPLY
10
+V_DD
+V_DC
V_DD
Voltage sense

FIGURE 1

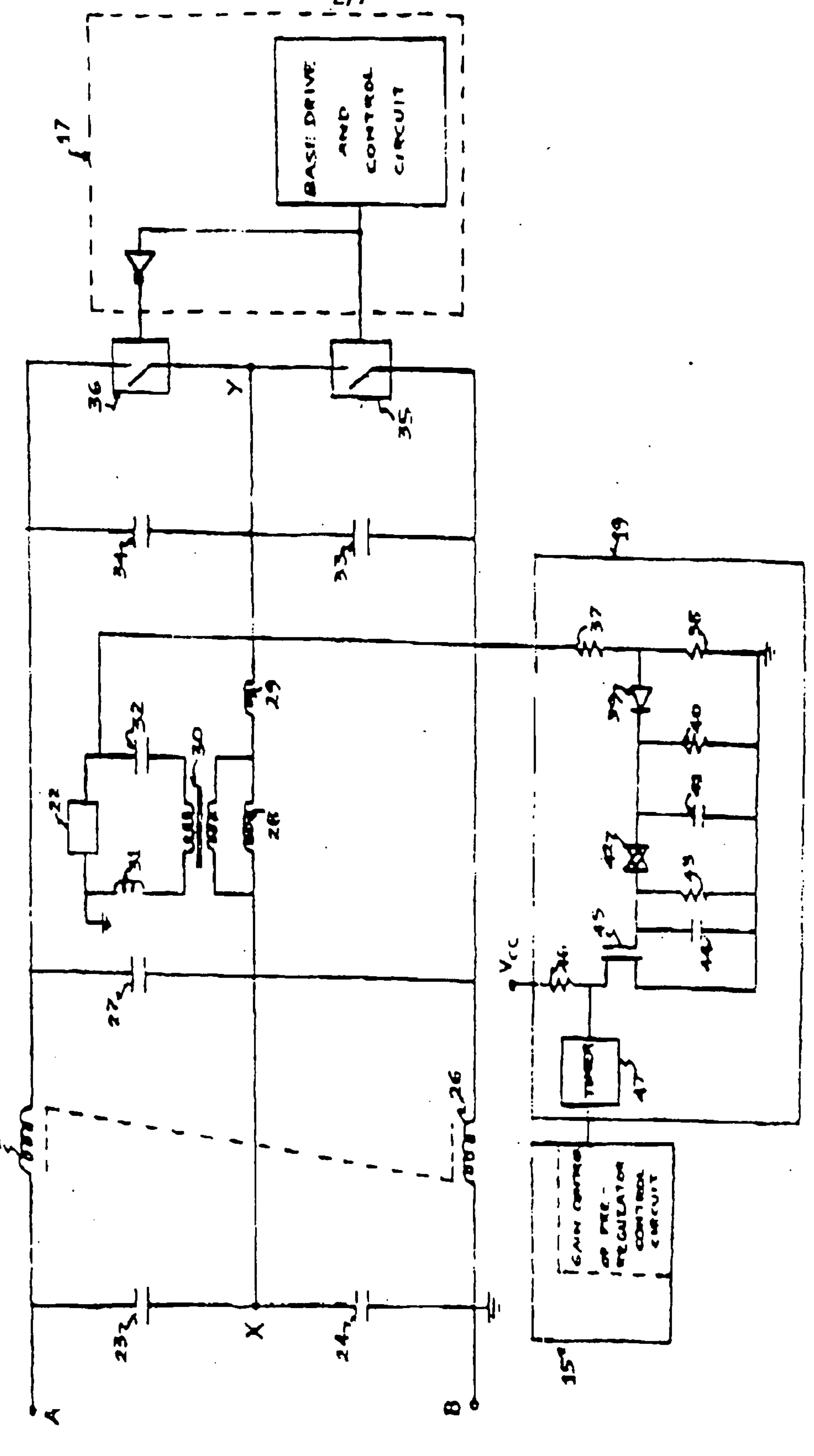
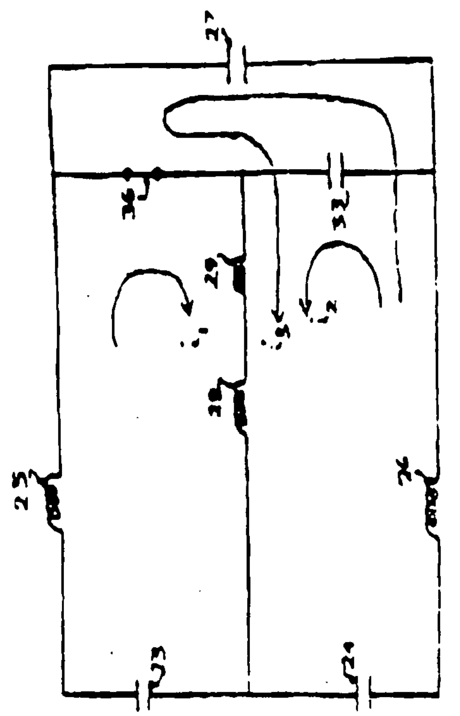

BASE DRIVE AND CONTROL CIRCUIT
17
36
35
Y
X
A
B
23
24
25
26
27
22
28
29
30
31
32
33
34
19
37
38
39
40
41
42
43
44
45
46
47
TIMER
Vcc
GAIN CONTROL OF PRE-REGULATOR CONTROL CIRCUIT
15

FIGURE 2




HOT RESTRIKE MODE

FIGURE 4

BASIC AND MODIFIED SINGLE ENDED CLASS-E TOPOLOGY

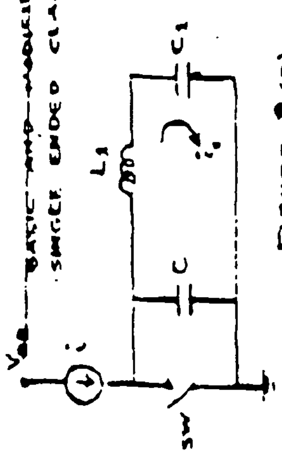



FIGURE 3(a)

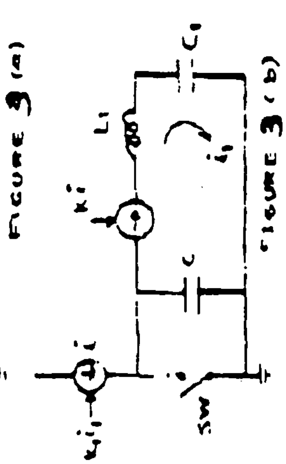
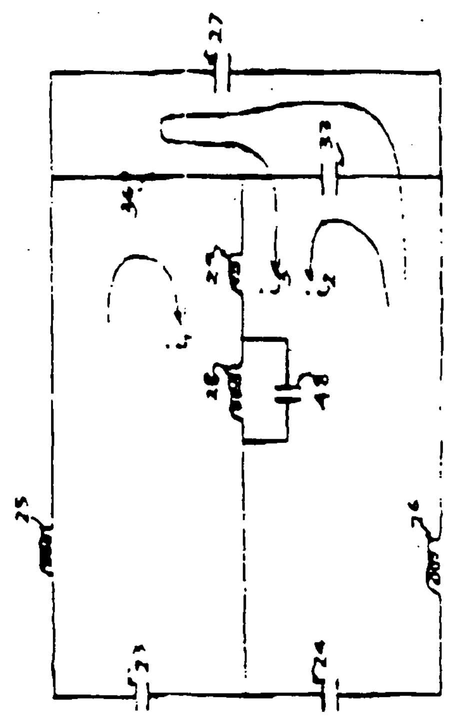



FIGURE 3(b)




NORMAL WORKING MODE

FIGURE 3

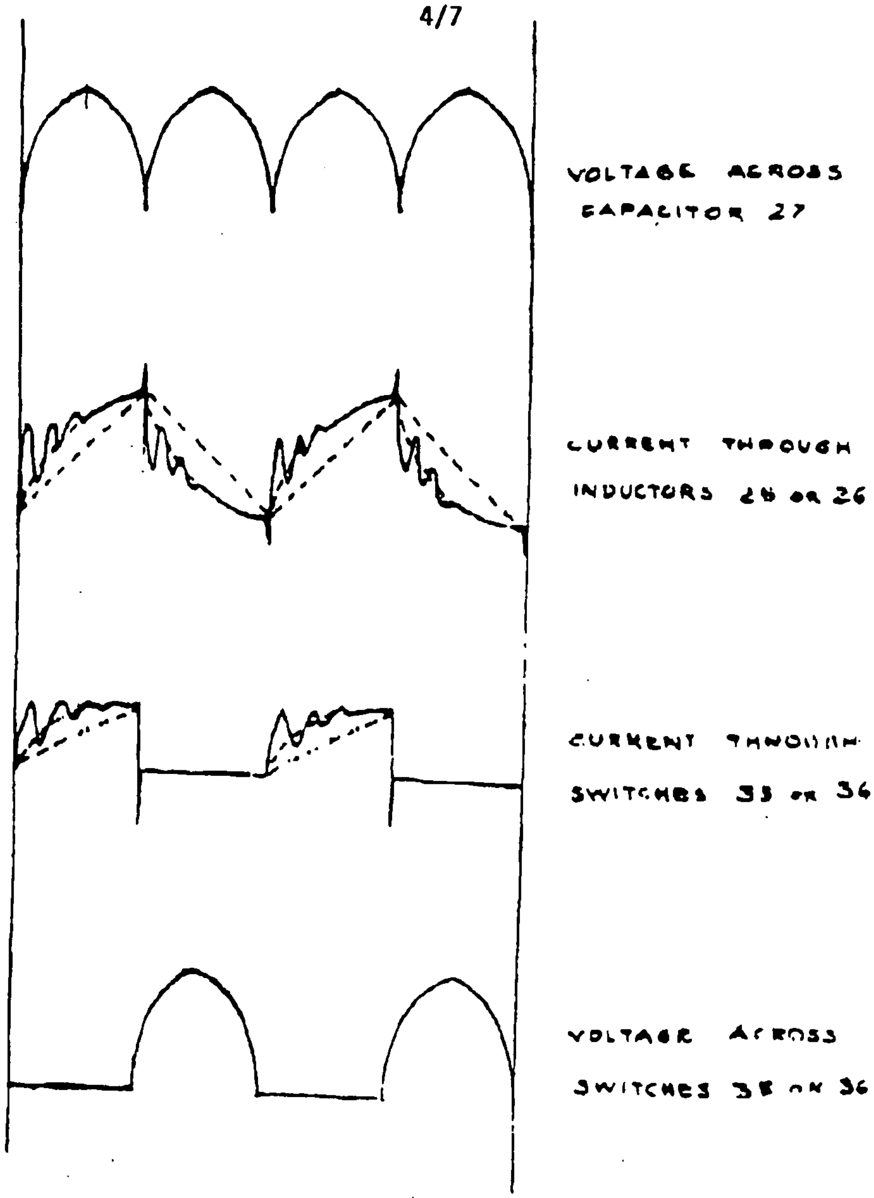

VOLTAGE ACROSS CAPACITOR 27
CURRENT THROUGH INDUCTORS 25 OR 26
CURRENT THROUGH SWITCHES 35 OR 36
VOLTAGE ACROSS SWITCHES 35 OR 36

FIGURE 5

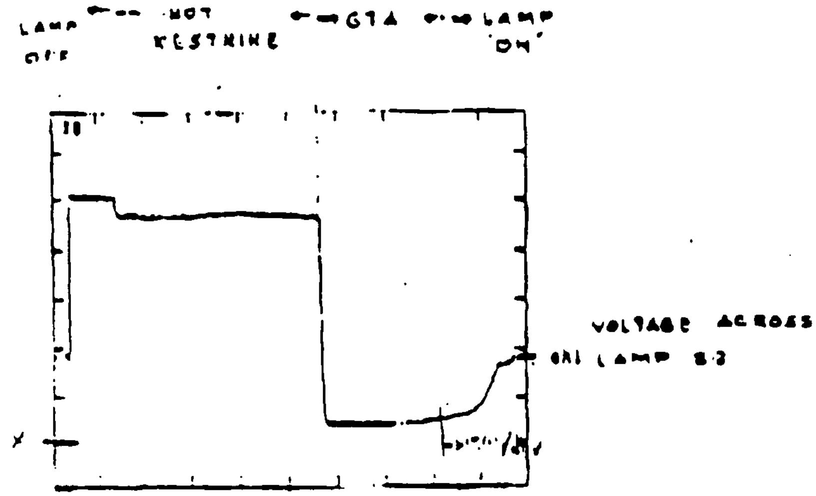



FIGURE 6 (a)

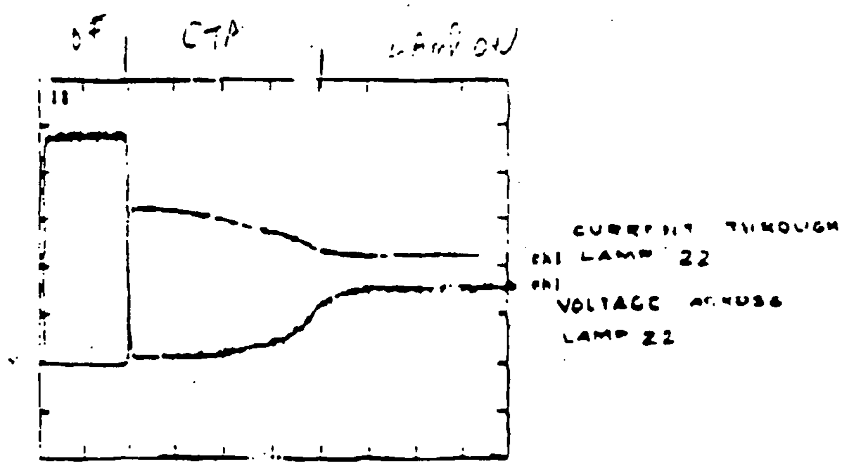



FIGURE 6 (b)

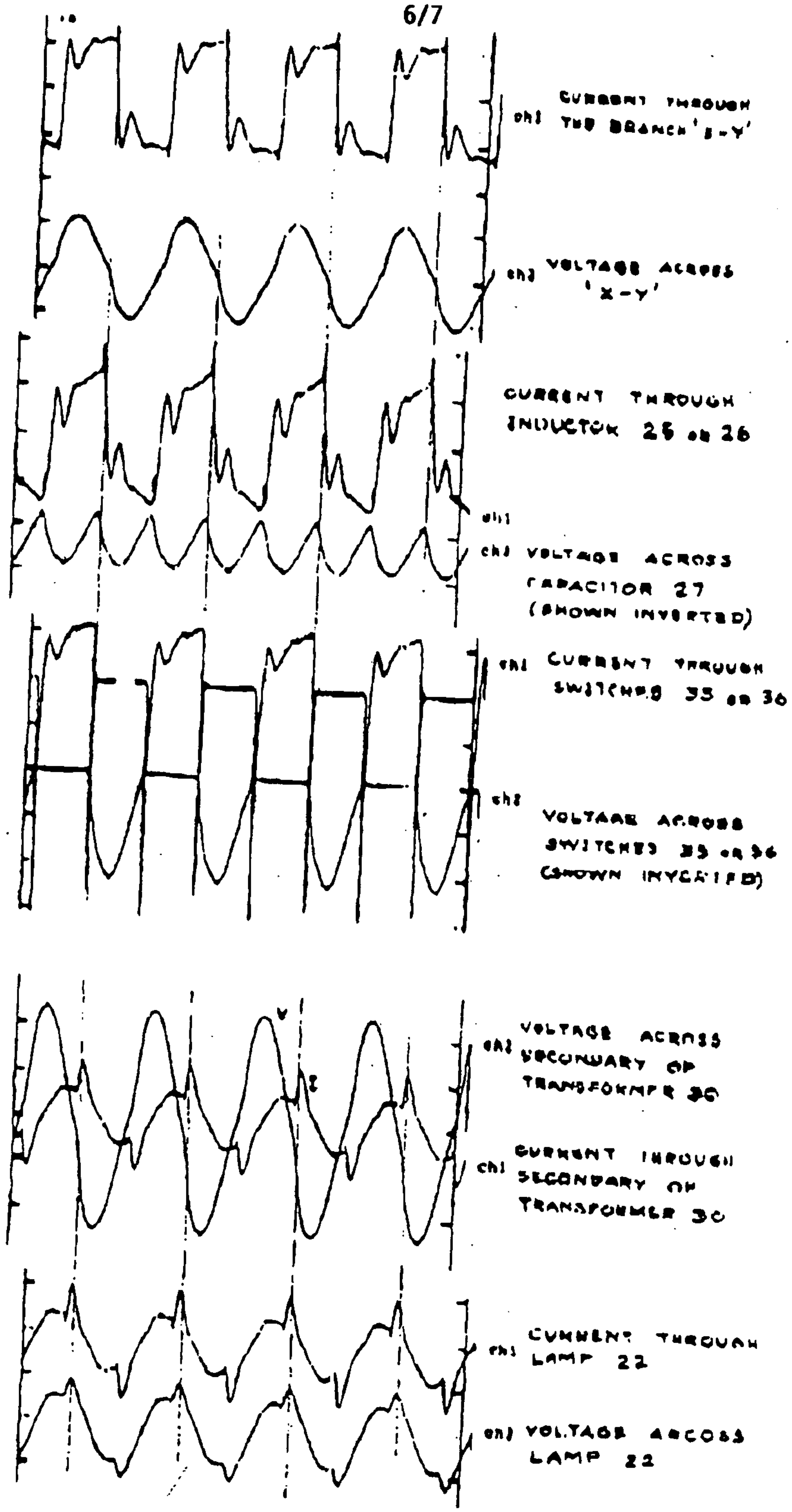

ch1 CURRENT THROUGH THE BRANCH 'X-Y'
ch2 VOLTAGE ACROSS 'X-Y'
CURRENT THROUGH INDUCTOR 25 OR 26
ch1
ch2 VOLTAGE ACROSS CAPACITOR 27 (SHOWN INVERTED)
ch1 CURRENT THROUGH SWITCHES 35 OR 36
ch2 VOLTAGE ACROSS SWITCHES 35 OR 36 (SHOWN INVERTED)
ch2 VOLTAGE ACROSS SECONDARY OF TRANSFORMER 30
ch1 CURRENT THROUGH SECONDARY OF TRANSFORMER 30
ch1 CURRENT THROUGH LAMP 22
ch2 VOLTAGE ACROSS LAMP 22

FIGURE 7

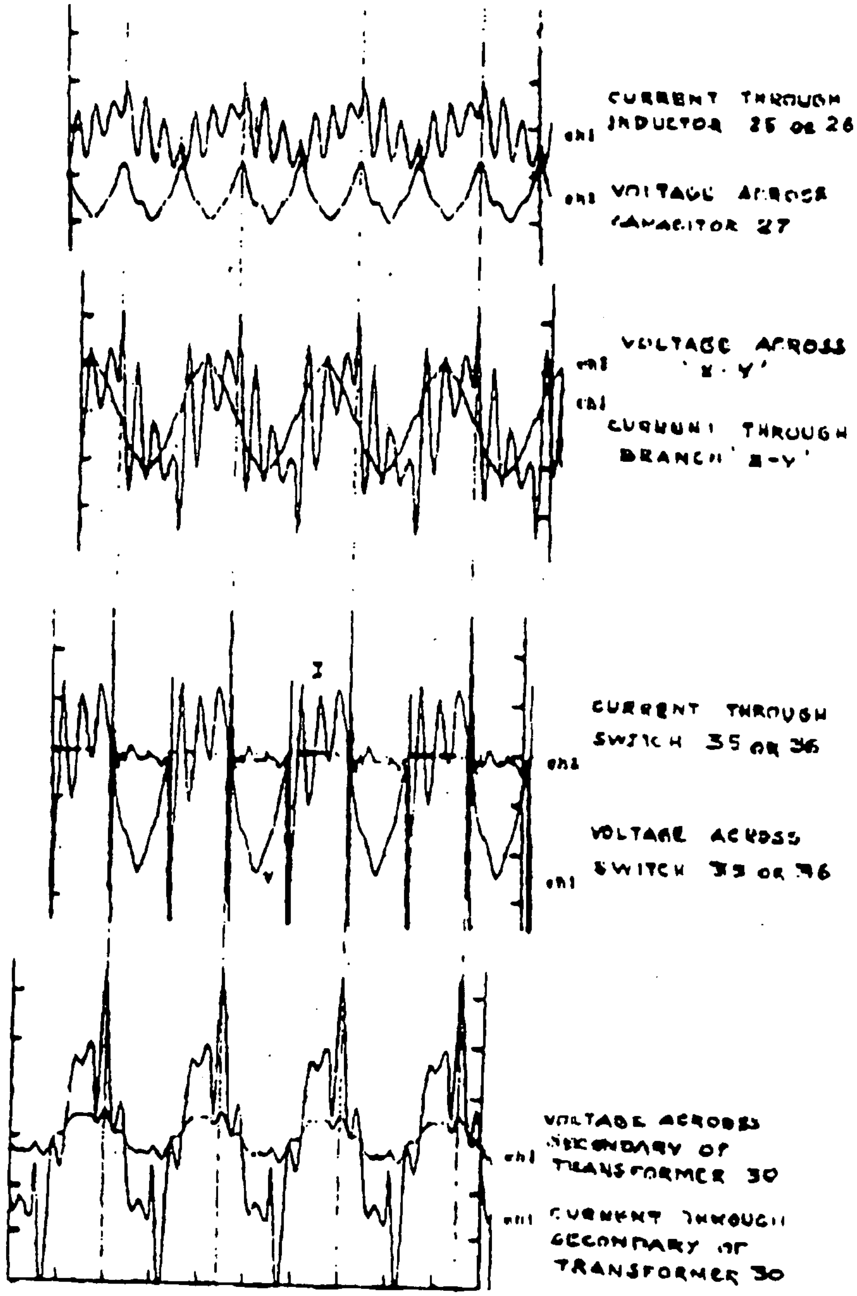

CURRENT THROUGH INDUCTOR 25 OR 26
ch1
ch2
VOLTAGE ACROSS CAPACITOR 27
VOLTAGE ACROSS 'X-Y'
ch2
ch1
CURRENT THROUGH BRANCH 'X-Y'
I
CURRENT THROUGH SWITCH 35 OR 36
ch2
VOLTAGE ACROSS SWITCH 35 OR 36
ch1
V
VOLTAGE ACROSS SECONDARY OF TRANSFORMER 30
ch1
CURRENT THROUGH SECONDARY OF TRANSFORMER 30
ch2

FIGURE 8

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/06769

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) :H05B 37/02
US CL : 315/209R, 224, 247, 290, DIG 7
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 315/209R, 224, 247, 290, DIG 7

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

None

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US, A 4,523,128 (Stamm et al.) 11 June 1985, See column 3, lines 35-58 and Figure 2. | 1-8 |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 29 AUGUST 1996 | 13 SEP 1996 |

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